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By

N. V. Grevtsev

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Argon-Arc and Electron-Ray Welding of Tantalum and Niobium

by

N.V.Grevtsev

A comparative investigation was made of welded tantalum and niobium joints, obtained during argon-arc and electron-ray welding and developed were recommendations on the welding of these metals by fusion.

The characteristics of tantalum and niobium welding are determined by their high melting point and high activity with respect to gases (oxygen and nitrogen) at higher temperatures. At a higher content of gases there is a substantial change in the mechanical characteristics: the ultimate strength rises during stretching and hardness, plasticity decreases. For example, for niobium and increase in oxygen content from 0.02 to 0.75% leads to an increase in hardness from HV 100 to HV 350.

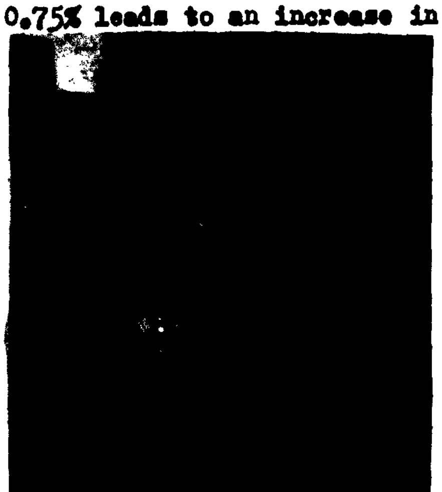

Fig.1.Installation for electron ray welding.

According to [1-6] a satisfactory quality of tantalum and niobium joints can be attained during argon-arc welding. But more stable qualitative results pertaining to welded joints are attained when welding in chambers with controllable atmosphere or with electron ray in vacuum.

This experiment devoted to the study of properties of welded tantalum and niobium joints was carried out at the lab of Theory of welding Processes at the A.A.Baykov Inst. of Metallurgy under the supervision of

member corresp.of the Academy of Sciences USSR N.N.Rykalin with the participation of cand.of tech.sc.G.N.Klebanov. Welding was done on the automatic ADSV-2 installation with argon jet protection of personnel and reverse side of seam and on the electron rays installation of the A.A.Baykov Inst.of Metallurgy. During argon-arc welding was used argon, containing 0.005% oxygen and 0.01% nitrogen.

The installation for welding with electron ray in vacuum (fig.1) consists of a high voltage VS 50/60 rectifier, vacuum chamber with electron gun, system for producing and controlling vacuum and electron ray control block.

The power source for the VS 50/50 represents a standard rectifier for x-ray installations and consists of high voltage transformer, tube rectifier block, battery of capacitors and control desk. Its rated current is 50 ma at a voltage of 50 kv.

The vacuum system consists of forevacuum pump VN-1 and diffusion unit VA-05-01 with a delivery of 250 liters/sec in a pressure range of $1\cdot10^{-5} - 2\cdot10^{-4}$ mm Hg.

For controlling the vacuum is used a standard vacuummeter VIT-1 with LT-2 tubes for the forevacuum and LM-2 tubes for high degrees of rarefaction.The vacuum system of the installation allows to obtain a vacuum in the chamber of $2\cdot10^{-5} - 8\cdot10^{-6}$ Hg. The entire pumping cycle takes up 25-35 min.

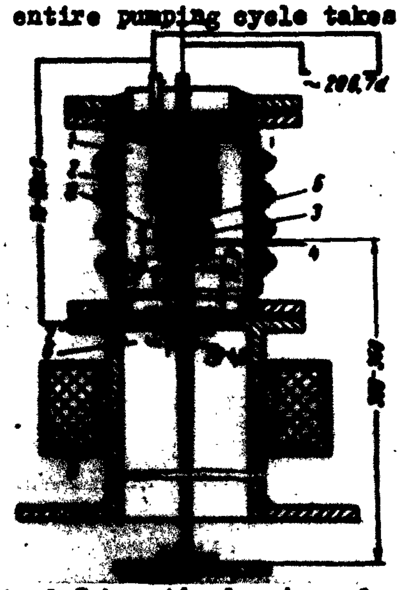

Fig.2.Schematic drawing of electron gun cross section.

The vacuum chamber is made of stainless steel 8 mm in thickness. It has two inspection hatches, protected by x-ray lead coated glass plates 10 mm in thickness,hatches for connecting diffusion and forevacuum pumps and for the installation of the electron gun, as well as opening for introduction into the chamber of rotating shaft and various metering devices (thermocouples etc.) In the chamber is provided an attachment

for fastening and shifting the welded units. Impetus is transmitted from an electric motor, mounted outside of the chamber. With the aid of interchangeable contrivances it is possible to realize forward as well as rotating movement of the joint during the welding.

In the upper part of the vacuum chamber is mounted the electron gun[1] (fig.2). The cathode block of the gun is mounted in a special ceramic insulator 2, intended for a voltage of up to 40-50 kv. The direct heating cathode 3 is made in form of a tumbler made of tantalum, on the upper part of whichis dusted on a layer of lanthanum hexaboride 4, possessing high emissivity. The cathode is heated by a tungsten spiral 5 made of wire with a diameter of 0.3 mm.

TABLE 1. Conditions for Welding Tantalum and Niobium.

1. Metal
2. Thickness mm
3. Current
4. ADS in a
5. ELS in ma
6. Welding rate in m/hr
7. ADS
8. ELS
9. Length of arc in mm
10. Accelerating voltage kv
11. Delivery of argon in 1/hr
12. Burner
13. Liner
14. Snout
15. Electrode
16. Material
17. Diameter mm
18. Tantalum
19. Niobium

SEE PAGE 3a FOR PICTURE OF TABLE 1.

REMARK: ADS-argon arc welding; ELS-electron ray welding
* welding with flanging of edges

The power required by the heater, does not exceed 130-150 w, which is perfectly sufficient for heating the cathode to 1600-1650°, corresponding to optimum degree of emission.

The anode block 6 is made in form of a tumbler of stainless steel ,cooled with

1.Construction of gun was developed by cand.of tech.sc.V.V.Gorbanskiy and Engr.A.F. Khudyshev.

TABLE 1

1. Металл	2. Толщина в мм	3. Ток		6. Скорость сварки в м/час		9. Длина дуги в мм	10. Ускоряющее напряжение в кв	11. Расход аргона в л/час			15. Электрод	
		4. АДС в а	5. ВЛС в ма	7. АДС	8. ВЛС			12. В горелке	13. В подкладке	14. В насадке	16. Материал	17. Диаметр в мм
Тантал 18.	0,5	80	60	39	26	1,0—1,5	15	250—300	200—250	100—120	W Вольфрам	2
		80	—	39	—	1,0—1,5	—	250—300	200—250	100—120	Ta Тантал	2
	0,8	270	—	90	—	1,5—2,0	—	300—320	250—300	130—150		2
		270	—	78	—	1,5—2,0	—	300—320	250—300	130—150	W Вольфрам	2
	1,0	270	80	54	20	2,0—2,5	16	300—320	250—300	130—150	Ta Тантал	3
	2,0	250	—	24	—	2,5—3,0	—	300—320	250—300	130—150	W Вольфрам	3
19. Ниобий	0,2*	110	30	73	33	0,5—0,8	15	250—300	200—250	100—120	W Вольфрам	1
	0,5	—	50	—	35	—	15	250—300	200—250	100—120	—	—
	0,75	90	—	39	—	1,0—1,5	—	250—300	200—250	100—120	W Вольфрам	2
	1,0	200	80	51,5	33	1,5—2,0	18	300—320	250—300	130—150		3

water or compressed air. Anode 7 is made of molybdenum or niobium. Assembly of the anode and cathode blocks is realized with the aid of flanged joints through copper liners.

First electron beam focusing is done with focusing niobium or molybdenum cap 8 situated under the cathode potential. At a distance of 12-15 mm from the surface of the cathode is placed the anode electrode 7 with opening of 2-4 mm. The second, much more precise focusing is realized with an electromagnetic lens 9, placed on the anode tumbler. The lens represents and electromagnetic coil (13000 turns, wire diameter 0.23 mm) placed in an armco-iron housing. Power and current control in the coil is realized with the aid of a special control block. The construction of the block includes a control system, deflecting system intended for shifting the ray during tuning (adjustment)

Electromagnetic and static focusing allows to obtain a heating spot with a diameter of about 0.6 - 0.8 mm at voltages of 14-16 kv and current of 50-60 ma. At currents of about 100 ma the minimum diameter of the spot constitutes 1.0 - 1.5 mm.

The construction of the electron gun provides the possibility of operation at voltages of up to 20 kv and currents up to 300 ma. Rectifier VS 50/50 is capable of working for a long time at a current of not more than 50 ma and during short term operation - up to 100 ma. Consequently, the maximum power, developed by the installation, can reach 2.0 kw. At an active spot area of 0.8 mm^2 the specific thermal flow will constitute 2.5 kw/mm^2 or 600 $kcal/mm^2$

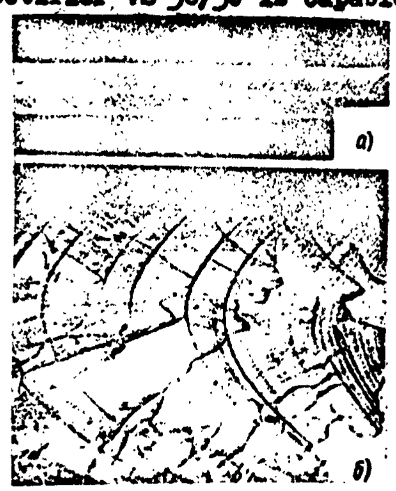

Fig.3. Outer view of welded tantalum seam 1 mm in thickness at argon arc welding during triple (a) and 50 times (b) magnification. Surface not pickled.

By virtue of its high chemical activity at higher temperatures tantalum and niobium require very thorough protection during the welding.

When these metals are heated the oxides and nitrides, contained in the surface layers, diffuse into the depths of the metal, as result of which there is an increase in hardness and a deterioration in the quality of welded joints .Consequently prior to welding it is necessary to thoroughly cleanse the edges of the sheets with emery board or pickle same in special reagents.

Welded tantalum and niobium joints, executed by argon-arc welding, are distinguished by excellent formation of seam. At good protection the seams have a clean shining surface with uniform flakiness. At a small increase (x35) on the surface is well visible the microstructure of the built up metal (fig.3) which indicates perfectly satisfactory protection against the effects of atmospheric oxygen and nitrogen. Orientation conditions of welding these metals are listed in table 1.

Ordinarily during the welding of tantalum and niobium in the role of nonconsumable electrode are used tungsten bars. In this operation was established the possibility of using for these purposes tantalum wire with a diameter of 3 mm. In this case,as in case of tungsten electrode, welding was carried out on direct polarity. When welding with a tantalum electrode the arc burns more stable, there is almost no spattering , the seam is formed better. Flashing off of the tantalum electrode is small and during the employed current densities not much higher than in case of a tungsten electrode.

Metallographic investigations and mechanical tests of welded joints showed, that the electrode material does affect the strength and hardness of joints (table 2) . When welding with tungsten electrode the hardness of seam metal is by 45-55 kg/mm^2 higher, than with a tantalum electrode. The hardness of the basic metal in the zone of thermal effect is also higher by approximately 10-25 kg/mm^2 (fig.4). The rise in hard ness takes place, evidently, as result of decrease in protection of the melted metal and near seam zone with argon at less stable arc burning between tungsten electrode and tantalum.

When making tensile tests on species welded together with tungsten and tantalum electrodes, their nature of destruction is also different. Samples of joints ,welded

together by tantalum electrode, were destroyed with relatively greater deformation, whereby the destruction took place along the metal of the seam and partially in the near seam zone. Joints, welded with tungsten electrode, disintegrated in a more brittle state and the fracture passed, as a rule, along the fusion line, and the grains of the built up metal became only slightly deformed.

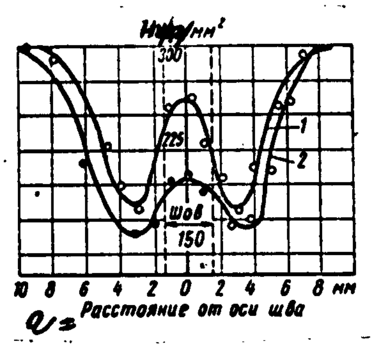

Fig.4. Hardness of welded joint made of tantalum with thickness of 1 mm made with tungsten (1) and tantalum (2) electrode; a-distance from axis of seam

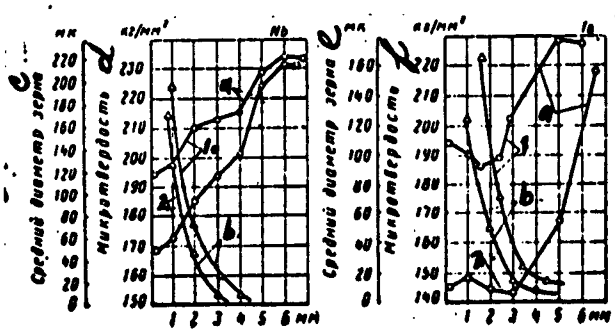

Fig.5.Change in hardness (a) and grain size (b) along the section of welded niobium and tantalum joints of 1.0 mm in thickness; 1-argon-arc welding; 2-electron beam welding. c-average grain diameter; d-microhardness; e-average grain diameter; f-microhardness.

The use of a tantalum electrode during welding of niobium,does not improve the quality of the welded joint. Furthermore the stability of the welding process decreases thereat. That is why niobium and niobium base alloys were hence being welded with tungsten electrodes only.

The microstructure of welded tantalum and niobium joints is characterized by quite large size grain of basic metal in the zone, directly adjoining the seam. On the metal 1 mm thick the zone of thermal effect has a width of 2-4 mm, but the section with large grains is considerably smaller (approximately 0.5-0.6 mm). When doing electron beam welding the maximum size of the grain in the zone of thermal effect is somewhat smaller, than during argon-arc (fig.5), which is connected with greater concentration of heat in the focal spot of the electron beam. This difference is especially noticeable on the tantalum, where it reaches double magnitude.

At a finely grained structure of the basic metal in the zone of thermal effect

1. Table 2. Mechanical Properties of Basic Metal and Welded Tantalum and Niobium Joints
2. Metal
3. Thickness mm
4. Welding method
5. Electrode material
6. Ultimate strength kg/mm^2
7. Basic metal
8. Welded joint
9. Bending angle in °
10. Basic metal
11. Welded joint
12. Microhardness kg/mm^2
13. Basic metal
14. Seam
15. Zone of thermal effect
16. Tantalum
17. Niobium
18. ADS
19. ELS
20. ADS
21. ADS
22. ADS
23. ADS
24. ELS
25. ADS
26. ELS
27. ADS
28. Tantalum
29. Tungsten
30. Tantalum
31. Tungsten
32. Tantalum
33. Tungsten
34. Tungsten

1. Механические свойства основного металла и сварных соединений тантала и ниобия

2. Металл	3. Толщина в мм	4. Способ сварки	5. Материал электрода	6. Предел прочности в кг/мм² — 7. Основной металл	8. Сварное соединение	9. Угол загиба в град. — 10. Основной металл	11. Сварное соединение	12. Микротвердость в кг/мм² — 13. Основной металл	14. Шов	15. Зона термического влияния
Тантал 16.	0,5	18. АДС	28. Тантал	77,4	45,5—51,0 / 48,5	180	180	220—240	185—194	185—220
		19. ЭЛС	—	77,4	50,0—54,5 / 52,1	180	180	220—240	145—148	150—200
	0,8	20. АДС	29. Вольфрам	55,7	27,2—38,2 / 33,6	180	180	—	—	—
		21. АДС	30. Тантал	55,7	36,6—39,3 / 38,1	180	180	—	—	—
	1,0	22. АДС	31. Вольфрам	81,2	50,0—60,0 / 55,4	180	180	275—300	215—260	180—280
		23. АДС	32. Тантал	81,2	56,4—62,6 / 57,7	180	180	275—300	190—205	170—260
		24. ЭЛС	—	62,4	46,3—49,5 / 47,9	180	180	275—300	175—200	200—240
Ниобий 17.	1,0	25. АДС	33. Вольфрам	61,5	44,2—45,5 / 44,7	180	180	233—247	191—204	208—217
		26. ЭЛС	—	61,5	42,8—48,3 / 45,3	180	180	233—247	169—175	175—220
	0,75	27. АДС	34. Вольфрам	63,0	37,0—43,1 / 40,7	180	180	215—230	210—215	166—203

*ADS = Argon Arc Welding
ELS = Electron Beam Welding

the welded joints, made by electron beam, have considerably lesser hardness (fig.5) This is connected with almost total absence of contamination of melted and heated to high temperatures metal with atmospheric oxygen and nitrogen. When doing electron beam welding in vacuum there is additional purification from toxic gaseous admixtures, contained in the basic metal, which is also instrumental in reducing the hardness of the metal in all sections of the welded joint.

About considerable contamination of the seam metal with gases during argon-arc welding with jet protection is being directly proven by the microstructure of welded tantalum and niobium joints (fig.6), consisting of large, basically polygonized sub-grains, in the interior of which is a number of etching figures, arranged in form of small chains of definite orientation. Thanks to these figures one can clearly distinguish the smelting (fusing) boundary of basic and built-up metal (fig.6c). At a greater increase (magnitude 800) (fig.7) is visible the form of these figures (triangles, rectangles, pentagons etc.) Most clearly do the etching figures appear in the built-up metal of welded joints of niobium/molybdenum alloy. The form of the etching figures here is most variegated and different in each grain. It should be mentioned that the greater number of etching figures with proper orientation is observed only in the metal, subjected to melting.

The formation of etching figures is usually connected with the occurrence of dislocation processes. Etching figures originate at points of dislocation exit, where all the admixtures in the metal are —— concentrated. For niobium this is show by [7]. After lasting annealing at higher temperatures, annealing promoting shifting of dislocations, was noticed a regrouping, appearance of new and disappearance of old etching figures. In report [8] etching figures appeared (dislocations) on casted tantalum, saturated with oxygen at higher temperatures. The outer appearance of dislocation figures, obtained in these operations, is very close to the ones revealed in welded seams. This indicates strong contamination of tantalum and niobium with ad-

mixtures, primarily oxygen. But the presence in the built-up metal of welded tantalum and niobium joints of a greater number of etching figures, distributed uniformly over the entire field of the grain, produces no harmful effect on the mechanical properties of the joint. In spite of the rise in hardness, the plasticity of the welded joint is retained at necessary level (bending angle in all instances 180° at a mandrel angle ,equal to the thickness of the metal). In addition,*during* uniform distribution of admixtures over the grain the formation of crystallization cracks is less probable, we mean cracks which originate normally and grow over the new polygonal boundaries of subgrains [9].

Mechanical testing of basic metal an welded tantalum joints established,that the nature of change in their strength at test temperature rise is identical (fig.8a) In this and in the other case is observed a sharp reduction in strength in temperature range up to 1200°.Beginning with 1100° the strength of the welded joint is practically no different from the strength of the basic metal. At a further temperature rise the intensity of strength reduction drops sharply (about 10 kg/mm^2 at 1200° and 5 kg/mm^2 at 1800°).

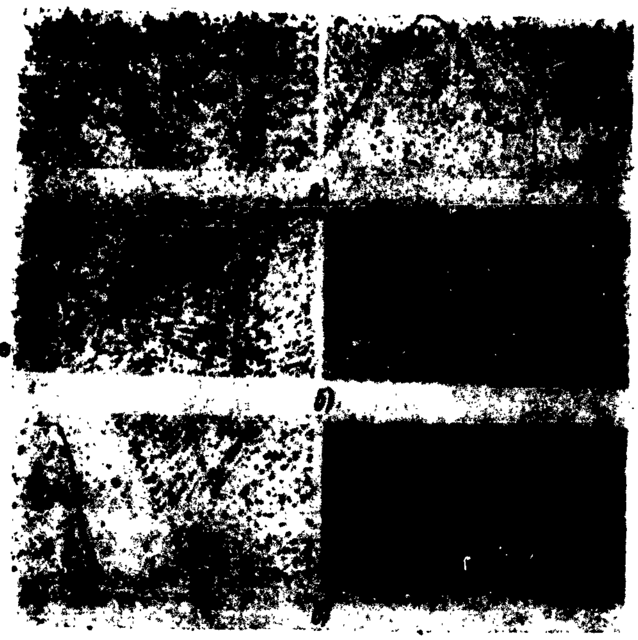

Fig.6.Microstructure of welded tantalum and niobium joints during argon-arc (left x 200) and electron-beam (right x 200) welding; a-niobium,built-up metal; b-tantalum, built-up metal; c-tantalum, fusion boundary.

The nature of change in niobium strength at higher temperatures is approximately the same as in case of tantalum (fig.8b). Here is also possible to distinguish two intervals with different strength reduction intensity. At temperatures of 400-800° is observed a certain drop in relative elongation per unit length. This can be connected with the occurrence of deformation aging pro-

cesses. However for accurate explanation of this phenomenon additional experiments must be conducted. An analogous phenomenon was observed during high temperature testing of tantalum [10] and molybdenum [11], although in this experiment it has not been discovered on tantalum.

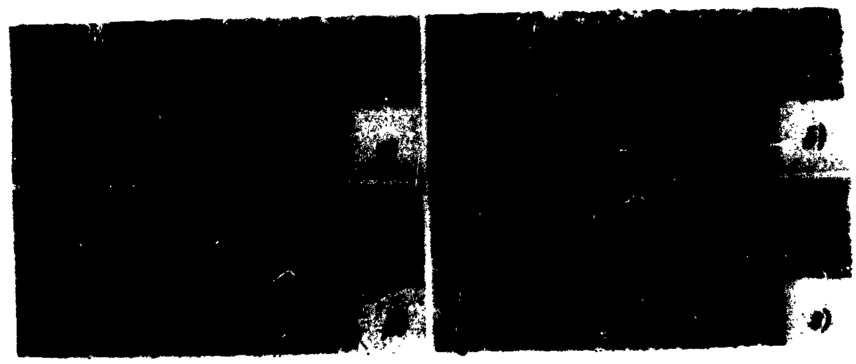

Fig.7. Etching figures in welded niobium seams, x 1000 (a), tantalum, x 800 (b) and niobium/molybdenum alloy, x 800 (c,d).

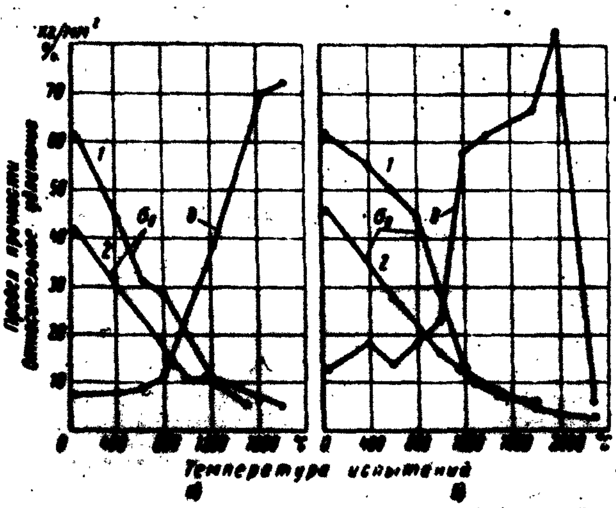

Fig.8. Mechanical properties of basic metal (1) and welded joints (2) tantalum (a) and niobium (b) at higher temperatures. c-ultimate strength, elongation per unit length; d-test temperature.

Conclusions

1. During the welding of tantalum and niobium with protective argon stream the metal of the seam and thermal effect zones are considerably saturated with oxygen and nitrogen (from the atmosphere) which leads to sharp rise in hardness in all sections of the welded joint as compared with joints obtained by electron-beam welding.

2. Contamination of the built up material with harmful gaseous admixtures is confirmed by the presence of etching figures in the microstructure of welded seams. But thanks to uniform distribution of of admixtures within each grain (as result of greater cooling rates in cooling welding bath) the welded joints retain sufficient plasticity.

3. The welding method exerts no noticeable effect on the ultimate strength of welded joints at room temperature. Destruction of the species during stretching takes place along the melting boundary and in the zone with maximum grain dimension during argon-arc welding and over the metal of the seam during electron beam welding.

4. During argon-arc welding of tantalum better results with respect to arc burning stability as well as plasticity of joints, are attained in case of a nonconsumable tantalum electrode. Niobium should be welded with tungsten electrode.

5. Change in strength of tantalum and niobium at higher temperatures is of identical nature. A sharp reduction in strength is observed in the range of up to 1200°; at much higher temperatures the strength drops less intensively. Welded tantalum and niobium joints at temperatures above 1100° are practically equi-strong to the basic metal.

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